

**S P E C I F I C A T I O N**

**SYSTEMS AND METHODS FOR TRACKING MOVING TARGETS AND  
MONITORING OBJECT POSITIONS**

## 5 BACKGROUND OF THE INVENTION

## Field of the Invention

[0001] The field of the invention relates to methods and systems for determining and monitoring object positions, and more particularly, to systems and methods for tracking target regions and monitoring object positions in medical procedures.

## Background of the Invention

[0002] Radiation therapy involves medical procedures that selectively expose certain areas of a human body, such as cancerous tumors, to doses of radiation. The purpose of the radiation therapy is to irradiate the targeted biological tissue such that undesirable tissue is destroyed. Radiation has also been used to obtain image of tissue for diagnostic or treatment purposes.

[0003] In a radiation treatment session, the position and movement of a target tissue can be monitored by an imaging system, such as a fluoroscopic imaging system, while radiation is delivered to the target tissue. This ensures that the target tissue is in a desired position while the radiation is being delivered. However, often soft tissue targets such as a variety of tumors are not visible in x-

ray fluoroscopic images. This is due to structures in front or behind the target tissue which are also visible in the x-ray images thus increasing the clutter to the level that the target tissue cannot be distinguished.

[0004] Internal radio-opaque markers have been used to aid physicians in  
5 identifying a target tissue under fluoroscopic imaging. The radio-opaque markers can be injected or implanted at desired sites within a patient, and they shows up as high contrast features in fluoroscopic images. By observing the positions of the internal radio-opaque markers in fluoroscopic images, a physician can determine a position of a target tissue. However, implantation of markers is  
10 intrusive to the patient, and it may not be practical or feasible in all cases.

[0005] Accordingly, systems and methods for tracking moving targets and monitoring patient positions without use of internal markers would be useful.

## SUMMARY OF THE INVENTION

15 [0006] In accordance with an embodiment of the invention, a method for determining a position of an object is provided. The method includes acquiring an input image of the object, enhancing a feature in the input image, registering the input image with a template, and determining a position of the object based on the registering. The feature in the input image may be enhanced by  
20 determining a composite image of previously acquired input images, and subtracting the composite image from the input image. For example, the

composite image may be determined by performing image averaging on the previously acquired input images. In one embodiment, the template is selected from a plurality of templates. In this case, the template that best matches an image in the input image is selected to be registered with the input image. The

5 method has applications in a wide range of medical procedures. By means of non-limiting example, the method may be used to dynamically target a tissue in a medical procedure. For example, the method may be used to dynamically target a target region in radiation therapy, in which a radiation treatment beam can be continuously positioned to follow the target region or gated to deliver radiation  
10 based on the position of the target region. One advantage of such method is that it does not require the use of markers to determine the position of the target region.

[0007] In accordance with yet another embodiment of the invention, a method for monitoring a position of an object is provided. In one embodiment, the

15 method includes providing a reference image of the object, acquiring an input image of the object, determining a composite image based on the reference image and the input image, and determining whether the object has moved based on the composite image. In one embodiment, the composite image may be determined by subtracting the reference image from the input image. By  
20 observing the contrast of the composite image, motion of the object may be detected. For example, a value associated with a contrast of the composite

image may be calculated, and be used to determine whether the object has moved. By means of non-limiting example, the method may be used to monitor a patient's position during a medical procedure. One benefit of such method is that it does not require the use of markers to determine the position of the patient  
5 body. Such method may also be used for gating a medical procedure. With respect to radiation therapy, a radiation beam may be deactivated when the value associated with the contrast of the composite image exceeds a certain prescribed threshold.

[0008] Other aspects and features of the invention will be evident from  
10 reading the following detailed description of the preferred embodiments, which are intended to illustrate, not limit, the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The drawings illustrate the design and utility of preferred embodiments of the present invention, in which similar elements are referred to by common reference numerals. In order to better appreciate how advantages and objects of the present inventions are obtained, a more particular description of the present inventions briefly described above will be rendered by reference to specific embodiments thereof, which are illustrated in the accompanying drawings.

Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered limiting its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings.

[0010] **FIG. 1** illustrates a fluoroscopic imaging system with which embodiments of the present invention may be implemented;

[0011] **FIG. 2** is a flowchart showing a process for targeting an object in accordance with an embodiment of the invention;

[0012] **FIG. 3** shows an algorithm for processing images in accordance with an embodiment of the invention;

[0013] **FIG. 4** shows examples of images generated during a treatment or diagnostic session performed in accordance with the process of **FIG. 2**;

[0014] **FIG. 5** is a flowchart showing a process for generating templates that may be used in the process of **FIG. 2**;

[0015] **FIG. 6** shows examples of images generated at different stages of the template generation process;

[0016] **FIG. 7** is a block diagram showing a system for processing images in accordance with an embodiment of the invention;

5 [0017] **FIG. 8** shows a motion signal chart and a gating signal chart;

[0018] **FIG. 9** shows a motion signal chart, a phase chart, and a gating signal chart;

[0019] **FIG. 10** is a flowchart showing a process for gating a medical procedure in accordance with an embodiment of the invention;

10 [0020] **FIG. 11** is a flowchart showing a process for monitoring a patient's position in accordance with an embodiment of the invention; and

[0021] **FIG. 12** is a diagram of a computer hardware system with which embodiments of the present invention can be implemented.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] Various embodiments of the present invention are described hereinafter with reference to the figures. It should be noted that the figures are not drawn to scale and that elements of similar structures or functions are

5 represented by like reference numerals throughout the figures. It should also be noted that the figures are only intended to facilitate the description of specific embodiments of the invention. They are not intended as an exhaustive description of the invention or as a limitation on the scope of the invention. In addition, an illustrated embodiment needs not have all the aspects or advantages  
10 of the invention shown. An aspect or an advantage described in conjunction with a particular embodiment of the present invention is not necessarily limited to that embodiment and can be practiced in any other embodiments of the present invention even if not so illustrated.

[0023] **FIG. 1** illustrates a fluoroscopic system 10 with which embodiments of  
15 the present invention may be implemented. The system 10 includes a fluoroscope 12, a processor 14, and a work station 16 having a display 18 and a user interface 20, such as a keyboard and/or a mouse. The processor 14 may be an integral component of the work station 16, or alternative, a separate component that is connected to the work station 16. The fluoroscope 12 is  
20 illustrated as a C-arm fluoroscope in which an x-ray source 22 is mounted on a structural member or C-arm 24 opposite to an imaging assembly 26, which is configured to receive and detect x-ray emitting from the x-ray source 22. The C-

arm 24 is capable of moving about a patient for producing two dimensional projection images of the patient from different angles.

[0024] During use of the fluoroscopic system 10, a patient 30 is positioned between the x-ray source 22 and the imaging assembly 26. A x-ray beam 32 is then directed towards a target region 34 within the patient 30, and is attenuated as it passes through the patient 30. The imaging assembly 26 receives the attenuated x-ray beam 32, and generates electrical signals in response thereto. The electrical signals are transmitted to the processor 14, which is configured to generate images in the display 18 based on the electrical signals in accordance with an embodiment of the present invention. During a treatment session, another radiation source 28 may be positioned adjacent the fluoroscopic system 10 for delivering treatment radiation 29 to the target region 34. Similar imaging systems or other types of imaging systems may also be used to implement embodiments of the present invention.

[0025] **FIG. 2** is a block diagram illustrating an embodiment of a process 200 for tracking a position of the target region 34 of the patient 30 as the target region 34 is being imaged using the fluoroscopic system 10 of **FIG. 1**.

[0026] To track a position of the target region 34 of the patient 30 undergoing a fluoroscopic imaging, a real-time input fluoroscopic image is generated using the fluoroscopic system 10 (Step 204). The target region 34 may include a tissue, such as a lung tissue or a heart tissue, that undergoes periodic physiological movements. Alternatively, the target region 34 may also include



tissue that does not undergoes periodic physiological movements, such as a bone tissue or prostate.

[0027] Next, the processor 14 processes the fluoroscopic image to enhance a feature, such as a moving feature of an object, in the fluoroscopic image (Step 5 206). By enhancing a moving feature in the input fluoroscopic image, contrast of an image of a moving object is enhanced while contrast of an image of a relatively stationary object is reduced. In the illustrated embodiment, the enhancement of the moving feature may be performed based on image averaging and image subtraction techniques.

10 [0028] In one embodiment, boxcar averaging technique may be used. Particularly, to obtain an enhanced input fluoroscopic image  $EIfI_n$  for the  $n$ th input fluoroscopic image  $IFI_n$ , a long term average of the previous input fluoroscopic images is calculated and subtracted from the  $n$ th input fluoroscopic image  $IFI_n$ , (i.e.,  $EIfI_n = IFI_n - \text{Avg}(IFI_{x=n-m \text{ to } x=n-1})$ , where  $m = \text{length of boxcar}$ ).

15 For example, the sixth input fluoroscopic image  $IRFI_6$  may be enhanced or modified by performing image averaging on the previous five input fluoroscopic images to obtain a composite image (i.e. an average image), and by subtracting the composite image from the sixth input fluoroscopic image  $RFI_6$ . As used in this specification, the term "composite image" includes an array of data that may

20 be stored in a medium, and therefore, is not limited to a displayed image.

[0029] In an alternative embodiment, the image averaging may be performed based on a weighted average prescribed as a function over time. For example, if

later input fluoroscopic images are to be accounted for more in the averaging, later input fluoroscopic images may be multiplied by a higher weighted factor during the image averaging, and vice versa. **FIG. 3** shows a recursive algorithm for enhancing a moving feature of an object in an image, in which the current

5 input fluoroscopic image is multiplied by a weighted factor (1-a) while the previous recursive average of the input fluoroscopic image(s) is multiplied by a weighted factor (a). The  $Z^{-1}$  represents a memory that holds one frame with one frame time delay. This results in an exponentially decreasing weighted average for the earlier samples. Other types of weighted averaging may also be used.

10 [0030] It should be noted that the process of enhancing a feature in the fluoroscopic image is not limited to the examples described previously, and that other modified versions of the process may also be used. For example, in another embodiment, the boxcar averaging may be performed on certain previous input fluoroscopic images (e.g., the last three images), instead of on all

15 of the previous input fluoroscopic images. In other embodiments, other functions or algorithms may be applied to any combination of the previous input fluoroscopic images and/or the current input fluoroscopic image before or after the image averaging is performed.

[0031] The processor 14 next registers the enhanced input fluoroscopic image

20 with a template (Step 208). In the illustrated embodiment, a sequence of templates is provided, and each of the templates contains an image of at least a portion of the target region 34 that is created at a certain time-point or a phase of

a physiological cycle. The processor 14 selects a template from the sequence of templates that best matches an image of the target region 34 in the enhanced input fluoroscopic image. The construction of the templates will be described later. As used in this specification, the term "phase" refers to a variable that  
5 represents, measures, or associates with, a degree of completion of a physiological cycle.

[0032] In one embodiment, the input fluoroscopic image is compared with the templates, and the template that best matches with an image in the input fluoroscopic image is registered or cross correlated with the input fluoroscopic  
10 image. In this case, the processor 14 performs an image comparison to determine which portion of the enhanced input fluoroscopic image best matches with each of the template images. Known techniques for performing image analysis, such as pattern matching, may be used. For example, if a template contains an image formed by 50x50 pixels, the processor 14 may perform a  
15 spatial analysis to determine a region (having 50x50 pixels) within the enhanced input fluoroscopic image that best matches the template image. The processor 14 then computes values representative degrees of match between the templates and an image in the input fluoroscopic image, and selects the template associated with the highest value to be registered with the input fluoroscopic  
20 image. The position of the image within the input fluoroscopic image that best matches the registered template may be stored in a computer-readable medium for later use.

[0033] In one embodiment, each cross correlation between the enhanced input image and a template results in a 2D correlation function with a correlation peak. In each correlation function, the location of the peak indicates the position of the target region 34, and the value of the peak indicates a degree of match  
5 between the input fluoroscopic image and the template. The template that provides the highest peak value is then selected as the matching template, and the corresponding peak position in the correlation function is used to determine the position of the target region 34.

[0034] Examples of an algorithm that may be used to search for the template  
10 that best matches the input fluoroscopic image will now be described. However, it should be understood that the determination of the template that best matches the input fluoroscopic image may also be performed using other algorithms or techniques. In one embodiment, the input fluoroscopic image is compared with all of the templates to determine the matching template. In another embodiment,  
15 instead of comparing the input fluoroscopic image with all of the templates, the input fluoroscopic image is compared with only a subset of templates. In this case, the subset of templates are selected such that their corresponding phase values (or time points of a respiration cycle at which they are generated) are centered around, or proximate to, the phase of the template that had the best  
20 match with the last input fluoroscopic image (i.e., from the last tracking cycle). Such technique increases the efficiency for registering the input fluoroscopic image with the template because an input fluoroscopic image and a template that

are collected at the same phase or time-point of a physiological cycle are likely to have similar image contrast. In another embodiment, if a match is found between the previous input fluoroscopic image and a template, and if the templates and the fluoroscopic images are generated at substantially the same phases or time-points of a physiological cycle, the next template in the sequence may be selected to determine if it matches with an image in the current input fluoroscopic image. If it is determined that the template does not match the input fluoroscopic image (i.e., the degree of match does not exceed a prescribed threshold), another template is then selected to determine if it matches with an image in the input fluoroscopic image. For example, the next template or the previous template in the sequence may be selected, until a match is found.

[0035] Once the input fluoroscopic image is matched with the template, the position of the target region 34 in the fluoroscopic image is determined (Step 210). Particularly, the position of the image in the input fluoroscopic image that matches with the template is the position of the target region 34. A marker may be displayed in the display 18 to indicate the position of the identified target region 34 in the input fluoroscopic image. For example, a frame or an outline having a similar shape as that of the corresponding registered template may be displayed in the input fluoroscopic image. The phase associated with the input fluoroscopic image can be determined based on the phase of the matched template. Alternatively the phase associated with the input fluoroscopic image

can be determined by a separate tracking mechanism, such as RPM external markers, available at Varian Medical System, Inc., Palo Alto, California.

[0036] The next real-time input fluoroscopic image is generated and the previously described process is repeated until the end of the session is reached

5 (Step 212). The templates and the input fluoroscopic images may be generated at same or different time intervals. For example, the templates may be generated at a shorter time interval as compared to that for the input fluoroscopic images, thereby allowing more matching variations between different sets of the input fluoroscopic images and the templates.

10 [0037] It should be noted that the steps described previously with reference to the process 200 can be carried out in substantially real-time. That is, the input fluoroscopic images can be processed to determine a position of the target region immediately or shortly after they are generated in step 204. Alternatively, the input fluoroscopic images can be generated in a batch, time-stamped, and  
15 stored for subsequent processing. In this case, the enhancing step 206, the registering step 208, and the determining step 210 can be performed subsequently.

[0038] **FIG. 4** shows examples of images generated at different stages of the dynamic targeting process described previously. An example of an input  
20 fluoroscopic image 400 created during a phase of a respiratory cycle, and its corresponding motion enhanced fluoroscopic image 402 created using the technique described with reference to step 206 are shown. As can be seen in

the figure, by subtracting the average image from the current input fluoroscopic image, the moving object(s), i.e., the lung tissue 404, is enhanced while the contrast of the relatively stationary object(s), i.e., the bone 406, is reduced. **FIG. 4** also shows a rectangular frame 408 displayed in the fluoroscopic image 402

5 identifying a region in the fluoroscopic image 402 that matches with the template 410. The template 410 is selected from a group 412 of available templates. The group 412 can include all of the generated templates, or alternatively, a subset of the generated templates, as discussed previously.

[0039] The construction of the templates will now be described. Various  
10 methods may be used to generate the templates. **FIG. 5** shows a process 500 for generating the sequence of templates in accordance with an embodiment of the present invention. First, the radiation source 22 of the fluoroscopic system 10 is positioned and aimed towards an area of the body that includes the target region 34, and a plurality of reference fluoroscopic images RFI is generated  
15 using the fluoroscopic system 10 (Step 502). The position and orientation of the x-ray source 22 relative to the patient 30 may be stored for later use.

Particularly, the position and orientation of the x-ray source 22 used during the template generation session may be used to set up the x-ray source 22 for generating the input fluoroscopic images. As a result, the image in the input  
20 fluoroscopic image would be similar to that in the template, thereby allowing matching of the template with the input fluoroscopic image. If the target region 34 includes a moving tissue, the plurality of reference fluoroscopic images is

preferably collected over a physiological cycle, such as a respiratory cycle or a cardiac cycle, of the moving tissue. In one embodiment, 120 to 200 reference fluoroscopic images are collected over a period of 12 to 20 seconds in order to capture movements of the target region 34 during a respiratory cycle. The  
5 collected reference fluoroscopic images are time-stamped and are then stored in digital format in a computer readable medium, such as a hard-drive, a CD-Rom, a diskette, or a server.

[0040] Next, the reference fluoroscopic images are associated with phases or time-points of a physiological cycle (Step 504). In one embodiment, the  
10 generated reference fluoroscopic images are time-stamped as they are generated in Step 502. A patient position monitoring system, such as that available at Varian Medical System, Inc., Palo Alto, California, may be used to detect physiological motion of the patient, and generates motion data as the reference fluoroscopic images are generated. The reference fluoroscopic  
15 images are then associated with phases or time-points of a physiological cycle based on their corresponding stamped time and the motion data. For example, the reference fluoroscopic images can be synchronized with the motion data to a common time line. In another embodiment, the reference fluoroscopic images may also be registered in phase with three-dimensional computed tomography  
20 images generated during a planning session (described below).

[0041] In Step 506, images of the target region 34 are identified in the respective reference fluoroscopic images. In one embodiment, the images of the



target region 34 may be determined manually by a user, such as a physician or a technician. In this case, the user examines each of the selected reference fluoroscopic images and identifies the target region 34 in each of the selected reference fluoroscopic images. For each identified target region 34 in the  
5 reference fluoroscopic images, the user may place a marker representative of the position of the target region 34 in the corresponding reference fluoroscopic image. For example, the user may operate the user interface 20 and place a frame around a region of interest (ROI) containing the target region 34 in the corresponding reference fluoroscopic image. Alternatively, the user may also  
10 draw an outline around a ROI having a shape that resembles the target region 34 in the corresponding reference fluoroscopic image. In this case, the outline may represent a boundary of the target region 34 to which treatment may be applied.

[0042] In another embodiment, the image of the target region 34 in the respective reference fluoroscopic images may be determined by projecting a  
15 three-dimensional (3D) treatment volume onto the respective reference fluoroscopic images. In this case, a number of 3D computed tomography (CT) images of the treatment volume are obtained such that they cover a period, such as a physiological cycle. The 3D CT images may be generated simultaneously with the sequence of the reference fluoroscopic images. Alternatively, the 3D CT  
20 images may be generated separately from the reference fluoroscopic images, in which case, the reference fluoroscopic images may subsequently be registered in phase with the 3D CT images. Conventional techniques may be employed to

register the sequence of the reference fluoroscopic images with the CT images.

PRM Respiratory Gating System, available at Varian Medical System, Inc., Palo Alto, California, may also be used to register the reference fluoroscopic images with the CT images.

5 [0043] The 3D CT images are then examined to determine the position of the target region 34 in the respective images. In one embodiment, the position of the target region 34 in each of the respective CT images is projected onto the respective two-dimensional (2D) reference fluoroscopic image using known transformation techniques. Based on the projected positions of the target region  
10 34 in the respective reference fluoroscopic images, ROIs containing images of the target region 34 can then be defined in the respective reference fluoroscopic images. For example, a rectangular frame circumscribing the target region 34 may be used to define a ROI. Alternatively, an outline having a shape that resembles the target region 34 may define a ROI.

15 [0044] Next, the reference fluoroscopic images are processed to enhance a moving object in the images (Step 508). The enhancement of a moving object may be performed using a similar technique described previously with reference to the input fluoroscopic images. In the illustrated embodiment, each of the reference fluoroscopic images in the sequence is modified based on image  
20 averaging and image subtraction techniques. Particularly, to obtain an enhanced reference fluoroscopic image  $ERFI_n$  for the  $n$ th reference fluoroscopic image  $RFI_n$  in the sequence, a long term average of the previous reference fluoroscopic

images is calculated and subtracted from the nth reference fluoroscopic image  $RFI_n$ , (i.e.,  $ERFI_n = RFI_n - \text{Avg}(RFI_{x=1 \text{ to } x=n-1})$ ). For example, the sixth reference fluoroscopic image  $RFI_6$  in the sequence is modified by performing image averaging on the previous five fluoroscopic images to obtain an average image, and by subtracting the average image from the sixth fluoroscopic image  $RFI_6$ . In one embodiment, the image averaging may be performed based on boxcar or recursive techniques. In alternative embodiments, the image averaging may be performed based on a weighted average prescribed as a function over time, as described previously.

[0045] Next, the images contained within the ROIs in the reference fluoroscopic images are stored as a sequence of templates (Step 510). The templates may be stored in a computer readable medium, such as a hard-drive, a CD-Rom, a diskette, or a server.

[0046] In the previously described embodiment, the motion enhancement is performed after the ROIs are determined in the reference fluoroscopic images. However, this needs not be the case. In an alternative embodiment, the order of the steps of enhancing a moving object and ROI determination can be different from the process 500. Furthermore, in another embodiment, instead of generating reference fluoroscopic images, digitally reconstructed radiographs (DRR) are produced from each reference 3D CT image for the direction of fluoroscopic image that will be used in treatment. In this case, the target volume

is projected in each DRR, and the DRRs are used as the reference fluoroscopic images in the same manner as the previous embodiment.

[0047] It should be noted that the above-described process 500 for generating the sequence of templates may be performed in the same session (e.g., a treatment session) in which the process 200 is being performed. Alternatively, the templates may be generated in another session that is carried out separately and prior to a treatment or diagnostic session.

[0048] **FIG. 6** shows examples of images generated at different stages of the template generation process 500 described previously. An example of a reference fluoroscopic image 600 created during a phase of a respiratory cycle, and its corresponding motion enhanced fluoroscopic image 602 created using the technique described with reference to step 508 are shown. As can be seen in the figure, by subtracting the composite image of previously generated reference fluoroscopic images from the current reference fluoroscopic image, the moving object(s), i.e., the lung tissue 604, is enhanced while the contrast of the stationary object(s), i.e., the bone 606, is minimized. Furthermore, **FIG. 6** shows a ROI 608 in the fluoroscopic image 602 that has been selected as a template 610. Note that the input fluoroscopic image 400 described previously with reference to **FIG. 4** is similar to the reference fluoroscopic image 600 because (1) the images 400 and 600 are collected from substantially the same angle and position relative to the patient 30, and (2) the input fluoroscopic image 400 and

the reference fluoroscopic image 600 are collected at substantially the same time-point of a physiological cycle.

[0049] **FIG. 7** shows a system 700 for performing the above described processes. The system 700 includes a template generation module 702 and an  
5 image matching module 704, either or both of which may be implemented using the processor 14 or a computer system. The template generation module 702 includes a phase association module 706, which associates the reference images 708 with phases or time-points of a physiological cycle. The template  
10 generation module 702 also includes a projection module 710 that projects a four dimensional treatment plan (3D treatment plan over time) onto the selected reference images 708, and a motion enhancement module 712 for enhancing a feature in the selected reference images 708. In one embodiment, the motion enhancement module 712 enhance a feature in the entire image for each of the  
15 selected reference images 708. In another embodiment, the motion enhancement module 712 enhances a feature in only the projected overlay on the selected reference images 708. Also in another embodiment, the motion enhancement module 712 is optional, in which case, the system 700 does not include the motion enhancement module 712.

[0050] The image matching module 704 includes a motion enhancement  
20 module 720 for enhancing a feature in the input images 722 that are generated during a treatment or diagnostic session. The image matching module 704 also includes a spatial and temporal matching module 724 for matching the input

images 722 with the generated templates 714. Particularly, for each of the input images 722, the spatial and temporal matching module 724 selects a template 714 that best matches an image in the input image 722, and generates an output 726. The output 726 includes the position ( $X_n$ ,  $Y_n$ ) of the sub-image in the input  
5 image 722 that best matches the template  $T_n$ , and an index  $n$  of the best-matching template  $T_n$ . The index  $n$  may be used to determine the time-point or phase of a physiological cycle at which the input image 722 is generated.

[0051] The previously described method allows a user determine a position of the target region 34 during a session without the use of a radio-opaque marker,  
10 and may be implemented using existing imaging systems. The method may be used by a physician to perform a wide range of operations or procedures.

[0052] Dynamic Targeting

[0053] In one embodiment, the position of the target region 34 obtained using the previously described process may be used as an input signal to control and  
15 aim a radiation treatment beam 29 towards the target region 34. In this case, the radiation treatment beam 29 is continuously positioned to follow the target region 34 based on the positions of the target region 34 identified in the fluoroscopic images. For example, the aim point of a treatment radiation beam may be controlled by a moving collimator based on data regarding the position of the  
20 target region 34 received from the processor 14. Alternatively a treatment couch supporting a patient can be moved to control a position of the target region 34 at which the beam 29 is directed.

[0054] Physiological Gating

[0055] In another embodiment, the above-described method may be used to detect a movement of the target region 34, based on which a medical procedure may be gated. Several examples of applications towards physiological gating will  
5 now be described with reference to radiation therapy. However, it should be understood by those skilled in the art that similar techniques or methods may be used to control other types of treatments or diagnostic procedures.

[0056] In one embodiment, the radiation source 28 may be gated to be turned on or off based on the positions of the target region 34 identified in the input  
10 fluoroscopic images. In this case, the position of the image within the input fluoroscopic image that is registered with the corresponding template may be used to determine if the target region 34 has moved beyond a prescribed threshold position. If the target region 34 remains within the prescribed threshold position, the radiation beam 29 is turned on, and if the target region 34 has  
15 moved beyond the threshold position, the radiation beam 29 is then deactivated.

[0057] **FIG. 8** shows an example of a motion signal chart 800 and a gating signal chart 802 that is aligned with the motion signal chart 800. The motion signal chart 800 may be created by using position data of the target region 34 obtained using the previously described process 200. A treatment interval 804  
20 may be defined by an upper bound 806 and a lower bound 808, as shown in the motion signal chart 800. In the illustrated example, the upper bound 806 has a value of 0.8 and the lower bound 808 has a value of -0.8. As shown in the gating

signal chart 802, any position of the target region 34 that falls outside the prescribed treatment interval 804 results in a "beam off" gating signal 810 that stops the application of radiation to the patient 30. Any position of the target region 34 that falls within the prescribed treatment interval 804 results in a "beam  
5 on" gating signal 812 that allows radiation to be applied to the patient 30.

[0058] In another embodiment, the radiation source 28 may be gated to be turned on or off based on the phase of a physiological cycle. In this case, the position vs. time history of the image within the input fluoroscopic image that is registered with the corresponding template may be used to determine a phase of  
10 a physiological cycle. If the target region 34 remains within a prescribed phase interval, the radiation beam 29 is turned on, and if the target region 34 has moved beyond the prescribed phase interval, the radiation beam 29 is then deactivated.

[0059] **FIG. 9** shows an example of a motion signal chart 900, a  
15 corresponding phase chart 902 for the target region 34, and a gating signal chart 904 that is aligned with the phase chart 902. The motion signal chart 900 may be created by using position data of the target region 34 obtained using the previously described method (i.e., at step 210). The phase chart 902 may be created based on a beginning and an end of a physiological cycle in the motion  
20 signal chart 900. The phase chart 902 shows the phase progression of a physiological movement of the target region 34 over time. A prescribed phase interval 906 may be defined by an upper bound 908 and a lower bound 910,



which are represented as dotted lines in the phase chart 902. In the illustrated example, the upper bound 908 has a value of  $185^{\circ}$  and the lower bound 910 has a value of  $25^{\circ}$ . According to the illustrated gating signal chart 904, any position of the target region 34 corresponding to a phase that falls outside the prescribed phase interval 906 results in a "beam off" gating signal 912 that stops the application of radiation to the patient 30. Any position of the target region 34 corresponding to a phase that falls within the prescribed phase interval 906 results in a "beam on" gating signal 914 that allows radiation to be applied to the patient 30.

10 [0060] In yet another embodiment, the radiation treatment beam may be gated to be turned on or off by associating the templates with treatment data. In one embodiment, certain templates may be associated with a "beam on" signal, while the rest of the templates are associated with a "beam off" signal. For example, templates generated within a prescribed treatment phase interval may  
15 be associated with a "beam on" signal, while templates generated outside the prescribed treatment phase interval may be associated with a "beam off" signal. In an alternative embodiment, in addition to the "beam off" and "beam on" signals, the treatment data may also include a "beam on duration" signal. In other embodiments, the templates may also be associated with treatment data  
20 that are commonly used in radiation therapy, such as beam shape data and radiation dosage data. During a radiation treatment session, real time input fluoroscopic images are obtained and are registered with the templates in

accordance with the previously described method. When an input fluoroscopic image is registered with a template that contains a "beam on" signal, the treatment radiation source 28 then directs a treatment radiation beam 29 towards the target region 34 for a duration prescribed by the corresponding "beam on

5 duration" signal. On the other hand, when an input fluoroscopic image is registered with a template that contains a "beam off" signal, the treatment radiation source 28 then holds off the treatment beam 29 and seizes directing radiation towards the target region 34. If a template also contains a "beam shape" data, when an input fluoroscopic image is registered with such template,

10 the processor 14 then directs a signal to a beam-shaping (e.g., a multi-leaf) collimator to change the shape of the treatment beam 29 based on the "beam shape" data. In one embodiment, to ensure that a correct treatment is being delivered to the target region 34, values may be computed to indicate a degree of correlation between the previously generated input fluoroscopic images and their  
15 corresponding registered templates. If the value indicates that there has been a high correlation in the temporal and/or spatial matching between the previously generated input fluoroscopic images and their corresponding registered templates, the registered template for the current input fluoroscopic image is likely to be correct, and treatment may be applied in accordance with the  
20 treatment data prescribed by the corresponding registered template.

[0061] In yet another embodiment, radiation may be delivered to the patient during a desired portion of a physiological cycle. In radiation therapy, it may be

desirable to apply the radiation beam 29 towards the target region 34 during a portion, such as a quiescent period, of a physiological cycle. For example, quiescent periods occur during the respiratory cycle at the ends of expiration and inspiration. In this case, the determined position of the target region 34 can be  
5 used to detect quiescent periods of physiological cycles. During the quiescent periods, the motion of the target region 34 slows down or may even cease for a fraction of a moment, thereby allowing a radiation treatment to be directed to the target region 34.

[0062] It should be noted that in the above described embodiments, the  
10 activation of a radiation beam may be gated in substantially real-time, or alternatively, in a predictive fashion. For example, based on a detected position of a target region and a degree of match between previous input fluoroscopic images and the templates, the processor 14 can predictively activate a radiation source (an example of predictive gating) so as to compensate for delay of  
15 activation time inherent in some x-ray systems. Predictive gating has been described in U.S. Patent Application Serial No. 09/893,122 referenced herein.

[0063] **FIG. 10** shows a method 1000 for gating a medical treatment based on a degree of detected motion of the target region 34 in accordance with an embodiment of the present invention.

20 [0064] To gate a medical treatment on the target region 34 of the patient 30 undergoing a fluoroscopic imaging, a real-time input fluoroscopic image is generated using the fluoroscopic system 10 of **FIG. 1** (Step 1004).

[0065] Next, a ROI in the input fluoroscopic image is determined (Step 1006).

In one embodiment, the ROI includes at least a portion of the target region 34, which can be a tissue targeted for treatment, or alternatively, any other tissue captured in the input fluoroscopic image. The ROI can be determined by a

5 physician during a treatment or planning session. For example, the ROI may be defined by a frame circumscribing a portion of the input fluoroscopic image.

[0066] Next, a composite image CI is created by subtracting the image in the ROI in the previous input fluoroscopic image from the image in the ROI in the current input fluoroscopic image (Step 1008). For example, for the third input

10 fluoroscopic image  $IFI_3$  generated in a sequence, a corresponding composite image  $CI_3$  is created by subtracting the image in the ROI in the previous input fluoroscopic image (i.e., the second fluoroscopic image  $IFI_2$ ) from the third input fluoroscopic image  $IFI_3$  (i.e.,  $CI_n = IFI_n - IFI_{n-1}$ ). It should be understood that this step needs not be performed for the first input fluoroscopic image in the

15 sequence since there is no previous input fluoroscopic image before the first input fluoroscopic image.

[0067] A value associated with a contrast of the composite image is next calculated over the ROI (1010). In one embodiment, the variance of the pixels in the composite image, which is associated with a contrast of the composite image

20 CI, may be calculated over the ROI, and may be used as a measure of the extent of motion undergone by the tissue within the ROI (e.g., the target region 34). In

other embodiments, different measures of the contrast in the composite image may be used.

[0068] A beam gating signal is determined based on the calculated value (1012). Since an image of an object in the ROI having low contrast indicates that the object has not moved significantly over time, and vice versa, a radiation beam may be disabled when the calculated value (associated with the contrast of the composite image in the ROI) exceeds a certain threshold, and be enabled when the value is below the threshold. In one embodiment, if the calculated value  $m > T \cdot A$ , then a radiation beam is disabled, and vice versa, where  $T$  is a prescribed threshold value, and  $A$  is a normalization factor for compensating for changes or daily variations in the operation of the fluoroscopic imaging system. One possible value for  $A$  is  $A = |\max m(t) - \min m(t)|$  where  $\max m(t)$  and  $\min m(t)$  are derived from observing  $m$  over a recent physiological cycle, such as a respiratory cycle or a cardiac cycle.

[0069] The next real-time input fluoroscopic image is generated and the previously described process is repeated until a sufficient radiation has been delivered to the target region 34 (Step 1014).

[0070] Target Object Position Monitoring

[0071] Besides dynamically targeting a moving object and gating a medical procedure, methods similar to that described previously may also be used to monitor or determine the position of a target object during a session. The target object may be a patient or an internal organ.

[0072] In one embodiment, a position of the object 30 may be determined using a method that is similar to that discussed previously with reference to **FIG. 2**. In this case, instead of generating a sequence of templates, one template is generated using the process 500 discussed previously. In this case, a portion of the reference fluoroscopic image containing the target object (i.e., object that is not expected to move beyond a certain prescribed threshold during a session) is selected as the template. During a treatment or diagnostic session, input fluoroscopic images of the target object 30 are analyzed and compared with the template to determine the position of the object in the input fluoroscopic images.

For example, the processor 14 may perform image analysis to determine a portion in each of the input fluoroscopic images that best matches with the template. The position of the matched portion in each of the input fluoroscopic images represents the position of the object. By observing the determined positions of the object in the input fluoroscopic images, one can determine how much the target object 30 has moved during a session. With respect to radiation therapy, if it is determined that the object 30 has moved beyond a certain prescribed threshold, the radiation beam 29 may be deactivated.

[0073] In certain situations, it may be desirable to determine that there is target object movement, and it may not be necessary to determine how much an object has moved. **FIG. 11** shows a method 1100 for target object position monitoring (i.e., determining whether there is target object movement) in accordance with an embodiment of the present invention. First, the radiation

source 22 of the fluoroscopic system 10 and the image detector is positioned and aimed towards the target object 30, and a reference fluoroscopic image RFI is generated using the fluoroscopic system 10 (Step 1102).

[0074] Next, a portion of the reference fluoroscopic image is selected as a ROI (Step 1104). Particularly, the portion of the reference fluoroscopic image should contain an image of a target object, that is expected to be held relatively stationary during a treatment or diagnostic session. The position of the ROI in the reference fluoroscopic image may be stored in a computer-readable medium for later use.

10 [0075] To perform target object position monitoring during a treatment or diagnostic session, a real-time input fluoroscopic image  $IFI_n$  is generated using the fluoroscopic system 10 (Step 1106). In the illustrated embodiment, the reference fluoroscopic image and the input fluoroscopic image are generated in the same session with the patient 30 staying in substantially the same position.

15 Alternatively, the reference fluoroscopic image and the input fluoroscopic image may be generated in different sessions. In this case, the x-ray source 22 and image detector are set up such that its position and orientation relative to the patient 30 are substantially the same as those in which the reference fluoroscopic image was generated.

20 [0076] In Step 1108, the current input fluoroscopic image  $IFI_n$  is subtracted from the reference fluoroscopic image RFI over the ROI to obtain a composite image  $CI_n$  (i.e.,  $CI_n = IFI_n - RFI$ ). In other words, a portion of the input

fluoroscopic image  $IFI_n$  having the same position as the ROI in the reference fluoroscopic image RFI is selected and subtracted from the image in the ROI to obtain the composite image  $CI_n$ .

[0077] The composite image  $CI_n$  is then analyzed to determine whether there  
5 has been target object movement (1110). If there has been target object movement, the pixels in the composite image  $CI_n$  should have an increase in contrast. The target object 30 may be considered to have moved if the contrast increase is above a certain prescribed threshold. With respect to radiation therapy, the radiation beam 29 may be deactivated when the contrast increase is  
10 above a prescribed threshold.

[0078] The next real-time input fluoroscopic image is then generated and the previously described process is repeated until the end of the session is reached (Step 1112).

[0079] The above-described target object position monitoring and  
15 determination may be performed in conjunction with the dynamic targeting or gating of a medical procedure described previously. Alternatively, other techniques for monitoring or determining a target object position, such as those described in U.S. Patent Application Serial No. 09/893,122, may also be used. The entire disclosure of the U.S. Patent Application Serial No. 09/893,122 is  
20 expressly incorporated by reference herein.

[0080] Computer System Architecture



[0081] **FIG. 12** is a block diagram that illustrates an embodiment of a computer system 1200 upon which an embodiment of the invention may be implemented. Computer system 1200 includes a bus 1202 or other communication mechanism for communicating information, and a processor 1204 coupled with the bus 1202 for processing information. The processor 1204 may be an example of the processor 14 of **FIG. 1**. The computer system 1200 also includes a main memory 1206, such as a random access memory (RAM) or other dynamic storage device, coupled to the bus 1202 for storing information and instructions to be executed by the processor 1204. The main memory 1206 also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor 1204. The computer system 1200 further includes a read only memory (ROM) 1208 or other static storage device coupled to the bus 1202 for storing static information and instructions for the processor 1204. A data storage device 1210, such as a magnetic disk or optical disk, is provided and coupled to the bus 1202 for storing information and instructions.

[0082] The computer system 1200 may be coupled via the bus 1202 to a display 1212, such as a cathode ray tube (CRT), for displaying information to a user. An input device 1214, including alphanumeric and other keys, is coupled to the bus 1202 for communicating information and command selections to processor 1204. Another type of user input device is cursor control 1216, such as a mouse, a trackball, or cursor direction keys for communicating direction

information and command selections to processor 1204 and for controlling cursor movement on display 1212. This input device typically has two degrees of freedom in two axes, a first axis (e.g., x) and a second axis (e.g., y), that allows the device to specify positions in a plane.

5 [0083] The invention is related to the use of computer system 1200 for processing images. According to one embodiment of the invention, such use is provided by computer system 1200 in response to processor 1204 executing one or more sequences of one or more instructions contained in the main memory 1206. Such instructions may be read into the main memory 1206 from another  
10 computer-readable medium, such as storage device 1210. Execution of the sequences of instructions contained in the main memory 1206 causes the processor 1204 to perform the process steps described herein. One or more processors in a multi-processing arrangement may also be employed to execute the sequences of instructions contained in the main memory 1206. In alternative  
15 embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement the invention. Thus, embodiments of the invention are not limited to any specific combination of hardware circuitry and software.

[0084] The term “computer-readable medium” as used herein refers to any  
20 medium that participates in providing instructions to the processor 1204 for execution. Such a medium may take many forms, including but not limited to, non-volatile media, volatile media, and transmission media. Non-volatile media

includes, for example, optical or magnetic disks, such as the storage device 1210. Volatile media includes dynamic memory, such as the main memory 1206.

Transmission media includes coaxial cables, copper wire and fiber optics, including the wires that comprise the bus 1202. Transmission media can also  
5 take the form of acoustic or light waves, such as those generated during radio wave and infrared data communications.

[0085] Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, or any other magnetic medium, a CD-ROM, any other optical medium, punch cards, paper tape, any  
10 other physical medium with patterns of holes, a RAM, a PROM, and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave as described hereinafter, or any other medium from which a computer can read.

[0086] Various forms of computer-readable media may be involved in carrying one or more sequences of one or more instructions to the processor 1204 for  
15 execution. For example, the instructions may initially be carried on a magnetic disk of a remote computer. The remote computer can load the instructions into its dynamic memory and send the instructions over a telephone line using a modem. A modem local to the computer system 1200 can receive the data on the telephone line and use an infrared transmitter to convert the data to an  
20 infrared signal. An infrared detector coupled to the bus 1202 can receive the data carried in the infrared signal and place the data on the bus 1202. The bus 1202 carries the data to the main memory 1206, from which the processor 1204

retrieves and executes the instructions. The instructions received by the main memory 1206 may optionally be stored on the storage device 1210 either before or after execution by the processor 1204.

[0087] The computer system 1200 also includes a communication interface 1218 coupled to the bus 1202. The communication interface 1218 provides a two-way data communication coupling to a network link 1220 that is connected to a local network 1222. For example, the communication interface 1218 may be an integrated services digital network (ISDN) card or a modem to provide a data communication connection to a corresponding type of telephone line. As another example, the communication interface 1218 may be a local area network (LAN) card to provide a data communication connection to a compatible LAN. Wireless links may also be implemented. In any such implementation, the communication interface 1218 sends and receives electrical, electromagnetic or optical signals that carry data streams representing various types of information.

[0088] The network link 1220 typically provides data communication through one or more networks to other devices. For example, the network link 1220 may provide a connection through local network 1222 to a host computer 1224 or to medical equipment 1226 such as a radiation beam source or a switch operatively coupled to a radiation beam source. The data streams transported over the network link 1220 can comprise electrical, electromagnetic or optical signals. The signals through the various networks and the signals on the network link 1220 and through the communication interface 1218, which carry data to and

from the computer system 1200, are exemplary forms of carrier waves transporting the information. The computer system 1200 can send messages and receive data, including program code, through the network(s), the network link 1220, and the communication interface 1218.

- 5 [0089] Although the embodiments of the systems and methods have been described with reference to fluoroscopic imaging, it should be understood that the systems and methods may also be implemented using other types of imaging. Depending on the type of imaging used, the previously described methods may be modified, and are intended to be within the scope of the present invention.
- 10 For example, if the type of imaging technique used is such that it can generate images of a target region with sufficient contrast or desired features, then the step (i.e., step 206 and 508) of enhancing a moving object in an image may not be necessary. Particularly, in other embodiments, if the contrasts or features of an image in the templates and the input images are such that they allow
- 15 registration between the templates and the input images, then the methods 200 and 500 may not include step 206 and 508, respectively.

- [0090] Although the methods have been described with reference to radiation treatment, it should be understood that the same or similar methods may also be used to perform other types of medical procedures. For example, the gating
- 20 methods described with reference to **FIGS. 8-10** may be used in various diagnostic imaging procedures as well as image-guided surgery in which movement of surgical instruments are controlled by the position of the target

object. In addition, besides real-time and predictive gating described previously, the above-described methods may also have applications in retrospective gating. In this case, the input fluoroscopic images or the processed input fluoroscopic images can be time-stamped and stored for future processing. For example, in  
5 three-dimensional imaging applications such as computed tomography, PET, and MRI, physiological data (e.g., position of target region or patient) obtained from the processed input fluoroscopic images can be used to retrospectively “gate” a reconstruction process. For this purpose, the raw data associated with the imaging application is synchronized to a common time base with the  
10 physiological motion data. Segments of the raw data that correspond to movement cycle intervals of interest are used to reconstruct the volumetric image thus minimizing the distortion and size changes caused by patient motion.

[0091] Furthermore, the method 200 is not limited to determining a position of a portion of a patient or animal body. The method 200 may also be used to  
15 determine a position of a non-animal body or other objects in a medical or non-medical environment.

[0092] Although particular embodiments of the present inventions have been shown and described, it will be understood that it is not intended to limit the present inventions to the preferred embodiments, and it will be obvious to those  
20 skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the present inventions. For example, the operations performed by the processor 14 can be performed by any combination

of hardware and software within the scope of the invention, and should not be limited to particular embodiments comprising a particular definition of “processor”. The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense. The present inventions are intended  
5 to cover alternatives, modifications, and equivalents, which may be included within the spirit and scope of the present inventions as defined by the claims.